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Influencing Modal Choice for Pollution Control:
Feasibility, Costs and Benefits
The Case of an Indian Megacity, Kolkata

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Abstract

Whilst the developed nations have used technology-forcing standards or market mechanisms (such as taxes) as their main tool for the control of transport pollution, transportation demand management (TDM) may have greater relevance for cities in poorer countries: and the choice of less polluting modes of travel is a crucial aspect of TDM.

With the help of a carefully selected sample of 3000 individuals residing in or commuting to the city of Kolkata, we have determined, from the travel behavior of the sample, the composition of the modes used by commuters in the city. Using measurements of the degree of pollution by all existing modes of transport, we have derived the total air pollution created by this modal structure. We have then looked at the extent to which we can make transport users shift to less polluting modes, and hereby evolved a number of *feasible* modal structures that would reduce air pollution. We determined the benefit (in terms of emissions reduction) and costs of changing the current modal composition to each of these alternatives. We were hereby able to arrive at several optimum modal compositions for Kolkata.

I. Introduction and Objectives

Passenger transport is bound to be a problem in Kolkata (see Map 1)[1], a city with an elongated shape that has little scope of expansion breadth wise, an extremely high population concentration at 23367 persons per square kilometer (Census, 2001)[2] and only 4 to 6 percent of its area covered by roads. As is the case in most megacities, Kolkata has an elaborate transport network that causes pollution. There is tremendous variety in the modes used in the city - among motorized forms of transport, the city has buses, trams, autos (or three-wheelers), taxis, shared taxis[3], the metro, a circular rail, water-ferries and local trains for public transport, and there are two wheelers and cars for private transport. There are a variety of buses – the state has regular, ‘special’ and ‘executive’ fleets, and private buses may be categorized as regular, chartered[4], school buses and minibuses[5]. Non-motorized forms of transport are rickshaws, bicycles and walking.

Although in Kolkata the petrol used is now totally lead free, other conventional measures have had little effect because of an insufficient, inefficient and corrupt I/M system. The newer vehicles are less polluting, but the turnover rate is very low and policies to phase out vehicles older than 15 years have not been implemented for political reasons. There are some vehicles that are running on LPG, but they remain few due to supply constraints, as well as a reluctance on the part of users to shift to this less polluting fuel.

Given these difficulties, it appears reasonable to explore the more coercive and less regulatory methods under transport demand management, which controls the quantity, mode or time of travel (and by doing so, reduces the total amount of pollution from transport). In addition, whilst standards and technical improvements reduce the emissions per vehicle per unit distance, they have no control over the total distance covered (that is, transport demand) and the modes used, hence they have limited control over the total

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[1] We are here considering only the Kolkata Municipal Corporation (KMC) area whose size is 196 square kilometers.
[2] Which, moreover, increases by another half million or so in the daytime.
[3] These are taxis that have a fixed route and carry five to six persons on a trip.
[4] These buses usually transport office goers.
[5] These are smaller than the regular size for private buses.

pollution created. Thus TDM, even if it does not replace the other policies, should certainly complement them Of the variety of TDM measures[6], we shall look at shifting transportation needs to less polluting modes (or modes that are less polluting *per person*, because they carry more people). This appears more meaningful in Kolkata's context because the other measures under TDM are either less feasible or less effective for Kolkata (Dutta, 2000).

In this paper we explore how modal choice can be influenced in Kolkata, and the extent of pollution reduction achievable through changes in modal choice[7]. Given this as our ultimate objective, we proceed as follows.

Our first step would be to determine the total pollution caused by the existing modal structure. For this we select a representative sample of 750 households and 280 non-resident commuters (amounting to 3000 individuals) with the help of appropriate sampling techniques. We obtain, for each mode, the distances traveled by the sample. Using data on pollution (per person per unit distance) by mode, we calculate the total pollution caused by the transport used by our sample, and from here extrapolate for the city.

We then determine, once again with the help of our representative sample, several ways in which the modal structure may be changed. We find out the benefit in terms of emissions reduction for each of the alternative modal structures, and see, for each feasible modal change, what requires to be done by the state to implement it, and the cost involved. From the cost figures and the benefits we arrive at the most cost effective (i.e. least cost per unit benefit) modal structure for the city.

Research on modal choice can be divided into two categories. The first looks at less polluting modes (either a single mode like the rail (Feitelson, 1994) or public transport in

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[6] Modal shifts, auto-free zones, no-drive days, land use policies, work week reduction, flexible work hours and peak hour charges

[7] Note that modal changes reduce pollution per person per mile traversed because the new modes are less polluting per se (eg. the metro), or because they carry more people (eg. buses).

toto (Kuhn and Lindau, 2000, Vasconcellos, 2001)) in an unstructured fashion, in order to suggest policy measures for inducing modal shift. This group includes an interesting paper by Thynell (2000) that looks at lifestyle changes that would make a commuter abandon his car and go for public transport. For India, such work has been done (amongst others) by Agarwal et al (1996), Bandyopadhyay (1996) and Bose et al (1997). The second category is more structured and analyses data, though such work may or may not arrive at concrete policy prescriptions. Bates (1998) sees how road prices can be changed to get commuters in London to use public transport, and the resultant economic and environmental benefits. Akinyemi and Medani (2000) carry out regression analysis to determine the relationship between motorcycle traffic and ambient air pollution. In the second category one should also include research which is not directly concerned with pollution, but which has relevance because it deals with modal choice. Dunphy (1997) uses Census and other secondary data in the U.S. to explore the reasons why people travel. Dickey analyses travel demand, including modal choice, using regression analysis. Vuchic (1992) compares various modes based on their attributes. Two papers, one by Pooley and Turnbull (2000) that uses British time series data and the other by Swait and Eskeland (1995) that uses cross section data in Sao Paulo, interestingly conclude that households' choice of travel mode is not sensitive to pricing or even travel time. There are a good number of mode choice models (such as the works of Sibal and Madhugiri (2000) and of Tiwari and Kawakami (2002)) that predict the percentage of commuters who will choose public transport versus those who will use private vehicles. The most common methodology used is the determination of probabilities using a logit function, and the determining variables are usually cost and service attributes of the various modes.

Our paper, as it is based on primary data and as it actually determines several crucial variables, belongs to the second (more concrete) category of research. Yet it takes into account all modes and sub-modes. In collecting data on travel behavior we have distinguished between a large range of trip purposes (not only work and education trips), and in obtaining data on incentives for modal shifts, we have similarly looked at all possible modal attributes (not only cost and travel time). We therefore feel that the data is both detailed and comprehensive. Secondly, we have evolved a methodology for correcting the overestimation that occurs when distance traveled is measured using data based on trip purpose, as sometimes more than one purpose is served on a trip. Thirdly, by evaluating (for each respondent in our sample) whether they would shift to alternative modes and what incentives they would require for the shift, we have only looked at *feasible* alternatives and their corresponding costs. And finally, this is a first attempt at measuring features such as the current modal structure of a city, the pollution that it creates, alternative structures and the corresponding pollution as well as cost efficiency for each, leading to clear-cut policy prescriptions.

II. Ranking of Modes According to Emissions

Data on pollution per person and per unit distance (Dutta et al, 2008) is presented in Table 1. This data has been obtained by adding individual pollution levels (obtained through a primary survey of all polluting modes used in Kolkata) of five pollutants (suspended particulate matter, nitrous oxides, sulphur dioxide, carbon monoxide and hydrocarbons. We rank the modes accordingly. To the list in Table 1, we have added the non-polluting modes that have been accorded the highest ranks. Table 2, therefore, gives the complete ranking of all modes of passenger transport, motorized and non-motorized, in terms of the level of pollution per person and per unit distance in descending order.

III. Household and Commuter Survey

We have taken a purposive sample of 750 households constituting 2720 individuals, and 280 commuters residing outside the KMC area. This proportion is based on the data that 0.47 million persons enter the KMC area, which has a population of 4.57 million, so that approximately 10.3 % of the number in the households has to be sampled from the commuters.

The households were selected with three main criteria in mind – (a) residential spread, (b) income groups and (c) nature of the locality. Also, as 22.6% of households are in sales in the KMC area (CMDA, 1999, p. 75), we have maintained that same percentage in our sample. This is because, of all the listed professions, this is the only one that can significantly influence modal choice[8], so that we wanted to keep a representative sample in the total.

The residential spread has been maintained by covering all the 15 boroughs in the KMC area, and maintaining the same population percentage in the sample as exists in the population itself. We have data on the per capita monthly household incomes in the KMC area, a data collected in 1997, and the residential areas they may correspond to. This is the only authentic data on household incomes in the KMC area. As the data was 7 years old at the point of the survey (conducted in October and November of 2004), we have used an inflation rate based on retail price indices in West Bengal to inflate the income ranges (Govt. of West Bengal, 2003-4, p. 169). Table 3 gives the ranges, the average income in the range and the percentages of households in this range.

The commuters were selected with the same income group proportions, but further, a male-female ratio of 72:28 was maintained, as this is the ratio obtained for commuters in general in the city. The latter had not been necessary for the households as the ratio becomes automatically close to that of the population when one is including every member of a household.

Travel behavior was recorded in great detail. Twelve categories of travel purpose[9] have been identified. For each category, there may be more than one destination - data on each destination has been recorded. For sales persons who have multiple work locations, no specific locations were recorded and average distances of multiple locations were taken. The frequency of travel was recorded in terms of the number of times travel to a certain destination took place in the last one year. The total distance of a destination was divided up according to the mode used, and further information (to be discussed subsequently) corresponding to each of these modes (under each destination) was obtained.

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[8] as sales persons travel a great deal and are far more efficient if they have a personal mode of transport
[9] Work, education, children's school, children's hobby/tutor, shopping, visiting friends, visiting relatives, health, entertainment, hobbies/clubs/religious, station/airport, other professional.

Finally, for our calculation of the total miles covered by our sample population we have collected data on trip combinations – that is, trips that involve more than one objective, and if so, whether the combination takes place in one direction, both directions or in a 'sequential' manner (such as when one starts with one destination, goes to the second, goes from there to the third, and then returns home). Further, the percentage of times of the minor trip/trips (that is, the one/s with the lower frequency) that one combines it with the major trip is recorded.

IV. Analysis of Data from Household and Commuter Survey

1. Derivation of Total Vehicular Pollution in KMC Area

The manner in which the data is collected, i.e. in terms of trip purpose, means that 'frequency' becomes overestimated as in actuality different destinations may be combined. This may be corrected by using the information on combination trips, which allow us to translate distance corrections into frequency corrections. Appendix A has the details.

After correcting the frequency data, which gives the number of trips, we multiplied it by two (to and fro) and then multiplied this with the distance to get, for each individual in the sample, the total distance traveled, by destination and within each destination, by mode. We then obtained the total distance (in terms of person-kilometers – that is, the kilometers covered by each person is counted separately) traveled by our sample of 2720 household members and 280 commuters by each mode (Table 4).

Interestingly, walking, followed by the regular private bus, covers the greatest distance and the metro and local train are in the third and fourth positions respectively at significantly lower values. We see that the rickshaw, although it is used largely *within* localities, is in the 5th position. The most polluting modes, the auto and the two-wheeler, are in the 6th and 9th positions respectively. The high pollution modes (1-6 in Table 2) are used for 6.3% of the distance, the medium pollution modes (buses and ferry) cover 28.87% of the distance and the zero pollution modes, 64.78%. Thus we can say that the current modal distribution in Kolkata is not unfavorable, and perhaps the major factor that keeps it thus is the high cost of much of the polluting forms of transport. However, the pollution levels would still decrease significantly if one could shift the high polluting modes to the medium or zero polluting modes. Secondly, and this is something that is not evident in this table, there is a danger of the medium or zero pollution users shifting to higher pollution modes (we shall observe this in subsequent analyses) in the near future – this, too, is something that has to be prevented.

We have then used the measure of pollution per kilometer and per person given in Table 1 for the different modes and distance covered by each mode in the sample given in Table 4 to obtain the total pollution caused by the sample. Of course, the non-motorized modes and the tram, metro, circular rail and local train emit zero pollution. This is given in Table 5.

Given that the KMC and commuter population is 5.04 million, i.e. 1680 times the sample size of 3000, Table 5 implies a total pollution of around two million kilograms in the KMC area. By the *total* pollution created, the regular private bus becomes a major culprit because it is used so much, and the auto and two-wheeler become the two most major polluters, in spite of the significantly lower person-kilometers of the two-wheeler.

2. Modal Shift Analysis

Our next objective is to see how we can ***change*** the modal structure in order to reduce the total quantity of pollution created by the present structure, as derived in the last section. We are not suggesting just any kind of modal structure, for providing that would not ensure that it is used. We are therefore trying to evaluate what sort of structure would actually be used by the travellers, and for that we have gone into the various features looked for in transport, and how we can entice transport users to shift to less polluting modes by improving on these features.

Let us first present the data on modal shift. Although during the survey we had collected data on a variety of aspects such as planned shifts to more polluting modes and plans to purchase private vehicles in order to fully understand the preferences of our sample, we here confine ourselves to our main objective of suggesting alternative modal structures that pollute less, and therefore we limit our discussion to possible shifts to less polluting modes, and incentives required for these shifts. We identified 10 features of transport that determine modal choice and hence would act as incentives for modal shift. They are:

a. a direct route (no transfers)
b. less waiting time
c. less travel time
d. waiting comfort (e.g. a better shaded bus stop)
e. travel comfort[10]
f. safe travel
g. good access (e.g. less walking to the bus stop)
h. lower cost
i. fringe parking (at the metro, ferry, circular rail and train stations) and
j. parking facilities for private vehicles (the opposite of which is parking restrictions and/or fines and/or fees).

We recorded, for each and every destination and every mode used for that destination that is in the most polluting category (two wheeler, auto, taxi, share taxi, hired car and private car), the incentives that would induce the user to shift to buses, the metro, the circular rail, the local train and the ferry. Tables 7-9 give the results.

Of the total kilometers covered by the more polluting modes (430553.2 kilometers), there are 330483.96 kilometers (about 77%) that *can* be converted to any of the five modes. This is given in Table 7.

Table 8 presents the kilometers of possible shift in terms of the more polluting modes

[10] which includes seating availability, seating comfort, smooth ride, less heat (AC/big windows), less pollution, ease of getting on/off and less closeness to other travelers.

currently being used. We see that very few users of personal vehicles (cars and two-wheelers) are willing to shift to anything much other than the metro, and even that percentage (at 30% for two-wheelers and 23% for cars) is not significant. The possible shift is particularly low for buses and the ferry. The percentages are larger for the other modes (auto, taxi, hired car and shared taxi) to all the five less polluting modes in general, although a shift to the metro is most easily accepted from *all* modes.

Table 9 gives the kilometers for the persons who have opted for bus as well as metro as alternative modes, whatever else they may have opted for, and the same for metro and rail, bus and rail, and finally, bus, metro and rail. This table will be crucial when we plan alternative modal structures and will be discussed subsequently.

Summing up the data on the incentives that would be required to achieve the shifts, we have concluded that travel, wait time and cost are very important criteria for transport choice. A direct route is also important as it has an impact on cost, time and the physical effort of changing modes. Those who can afford it choose personal vehicles because they provide comfort, and reduce travel time. For the motorized but non-polluting modes, one may specifically note that

- The metro is in greatest demand as an alternative, but only if access and a direct route are provided, and these can happen at a very high cost (yet the users would like to keep fares low)
- Buses are not substitutable in terms of accessibility but travel/wait time and comfort are deterrents there
- Access is difficult for rail, circular rail and ferry, and providing a direct route would be impossible for these. Keeping the cost down (for the traveler) would also be a problem for these modes.

!V. Alternative Modal Structures.

Our alternative plans will be developed using Tables 6-8. Firstly, we see that all of the kilometers being covered by the more polluting modes cannot be converted, whatever the incentive. Our alternative plan will be based on Table 6, which gives the kilometers that *can* be converted. As Table 6 gives the kilometers traveled by the sample, the corresponding amounts for the KMC area would be obtained by multiplying the values by a factor of 1680.

Although the bus does pollute at a 'medium' level, we retain it because, as we mentioned, it has features that none of the others have, there is already an elaborate bus system in the city as is the case for most cities, and it is cheap. The metro, though expensive to install, cannot be ignored as a zero-pollution mode with very attractive features. The rail is given tertiary importance as it provides better access (having a longer stretch) compared to the ferry and circular rail (which are all non-polluting). The ferry (currently) mostly runs across the river, carrying passengers who are coming from or going to Howrah station[11] – but it can be made to run along the river. However, from the responses, the ferry appears to remain a less attractive mode.

We are also assuming that the pollution levels calculated by us would remain at their current values. In reality, of course, these levels may change in some years, and differently for the various modes, and such changes can be incorporated in our structure. It may be added that recent efforts to reduce vehicular emissions in the city have failed (The Telegraph, July 8, 2003, June 3, 4,19, October 1, 2004 etc.).

Let us note that that concentrating on as few modes as possible reduces cost because of economies of scale. On the other hand, as respondents have not been willing to convert to all modes, we have to see the total number of kilometers converted to a particular (less polluting) mode, and then bring in another mode for the remaining kilometers. We shall also, therefore, consider cases where all five modes are developed.

We shall then be considering the following alternatives:

[11] The main train station

- Plan I – Shift what is possible to the metro
- Plan II – Shift what is possible to buses
- Plan III – Shift what is possible to the (suburban) rail
- Plan !V – Shift what can be to buses, and the remaining to the metro
- Plan V – Shift what can be to rail, and the remaining to the metro
- Plan VI – Shift what can be to buses, and the remaining to rail.
- Plan VII – Shift what can be to buses, then to rail, and the remaining to metro
- Plan VIII – Shift what can be to buses, and distribute the rest according to their convertibility percentages in the last row of Table 7.
- Plan IX - Distribute all according to their convertibility percentages in the last row of Table 7.

We use Tables 1, 7 and 8 to calculate the pollution saved for each plan. Table 7 gives us the maximum kilometers (of the sample) convertible to the five proposed modes, in terms of each of the current (more polluting) modes being used. We also know from the survey that 100069.24 kilometers of the total 430553.2 kilometers (around 23%) *cannot* be converted to *any* of the less polluting modes.

Also, Table 8 gives the kilometers for the persons who have opted for bus as well as metro, whatever else they may have opted for, and the same for metro and rail, bus and rail and finally bus, metro and rail. When we will consider a shift to the metro, say, after all the possible kilometers have been shifted to buses, we have to leave out those who have opted for both bus and metro as they have already been shifted to buses.

For plans I to III where the conversion is to only one mode, we use the convertible kilometers given in the final row of Table 7, and then calculate the quantity of pollution saved for the sample by multiplying the converted kilometers for each polluting mode (Table 7) by the pollution per person-kilometer of that mode (Table 1) and then adding up these to obtain the total pollution saved. For plans which include polluting modes (buses and ferry), we also subtract the pollution added by these[12] to get *net* pollution saved. We then multiply this by 1680 to obtain the total net pollution saved for the KMC area.

For plans IV to VI, where the conversion is first to one mode and then what remains is converted to another, we have to take into consideration Table 8, for there are persons who have agreed to shift to *both* the modes (whatever else they may have agreed to shift to), so we have to leave these persons out from those who have opted for the second mode.

In the case of plan VII, where the conversion is to buses, then to rail, and the remaining to the metro, the calculation is slightly more complicated. Let us use the actual numbers to illustrate this case. We first convert the maximum possible to buses (122554 kilometers), hence (330484 – 122554) = 207929 kilometers remain. Thus (see Table 8 with Table 7) (164554 – 77191.69) = 87362.31 kilometers can be converted to rail. Therefore (207929 – 87362.31) = 120556.69 kilometers remain for conversion to the metro. Now, to determine what *can* be converted to the metro, we subtract the kilometers that opt for (at least) metro and bus, and the kilometers that opt for (at least) metro and rail from the maximum amount convertible to the metro. However, as this implies the subtraction of those opting for a minimum of metro, rail and bus two times, we add the kilometers which opt for at least metro, rail and bus. That is (consult Table 8), the kilometers possibly convertible to the metro are

262395.4 – 92353.95 – 125126.79 + 76915.49 = 121830.15

[12] For buses we take an average of the pollution emitted by the seven types of buses.

But as 121830.15 > 120566.69, therefore the latter is fully convertible to the metro. Given the conversions, we similarly calculate the savings as well as additions to the pollution, and thence net savings.

For plan VIII, we convert what can be to buses, and distribute the rest according to their proportions in the last row of Table 7, and for plan IX all five modes are implemented in proportion to their percentages in the final row of Table 7. With the help of the converted person kilometers and the pollution data in Table 1, we calculate, as for the other plans, the net pollution reduction.

The values of net pollution saved in each plan for the KMC area are given in Table 9. We see that in terms of the reduction in pollution, plan VII (bus, rail, metro) is the best, followed by plans IX and VIII, in which all five modes are used. It appears, therefore, that combining the less-polluting and non-polluting modes is better that using one or two modes because the converted person-kilometers are less for the latter, resulting in a lower level of pollution reduction.

We then determined the costs of each of these plans. We have obtained (see Table 10) the .yearly costs (operating plus capital costs) per passenger kilometer of the five less- or non-polluting modes for 1989 (Roy, 1989), which we have updated to 2004 using the price indices for West Bengal (Govt. of West Bengal, 2003-4, p. 163).

If we now look at the incentives desired by the travelers to shift to the five modes, first, greater speeds and frequency of the buses is desired, as well as comfort. We assume that the removal of the low-occupancy modes on the road would automatically reduce the congestion and enhance speeds. Also, the greater number of buses (that would have to be provided to accommodate the greater number of bus users) would decrease the wait time. We have calculated, on the basis of consultations with experts, that the cost of increasing the comfort level of buses is Rupees 0 .01 per person kilometer.

For all the four other modes (metro, rail, circular rail and ferry), access is important. This, we propose, should be provided by a system of light rail transit (LRT) along the east-west corridor (spaced according to the total person-kilometers required) whose cost per passenger kilometer is Rupees 0.50 (Roy, 1989 and Govt. of West Bengal, 2003-4), and which is pollution-free. Now, the average distance for accessing the metro, which runs along the centre of the city is b/4, where b is the breadth of the city, and the average distance traveled on the metro is L/2, where L is the length of the city[13], hence for each person kilometer of travel on the metro, (b/4 ÷ L/2) person kilometers has to be traveled on the LRT. For the rail and circular rail, as they run along one side of the city, the average access distance would be half the breadth of the city (i.e. b/2 ÷ L/2). As regards the ferry, even if it runs along the breadth of the river, as ferry stops are fewer, a longer distance has to be covered to access the ferry. If this distance is double the distance for rail, access distance would be (b ÷ L/2). In all cases the standard length of travel is taken as L/2, as they all traverse (or, in the case of the ferry, are expected to traverse) the length of the city. These distances are then multiplied by the cost of having a LRT (Rupees O.50) to obtain access costs.

Cost was also stated as an important incentive for the modes other than bus, but actually the fares for the ferry and the three rails are all comparable to the bus fares or even lower. It appears that access costs are the concern – hence if access is made easier and by HOVs (LRT), the cost would not remain a factor.

The issue of a direct route, stated for all modes, is not solvable, as it would be impossible to provide direct routes on HOVs. However, if the greater number of buses translates into more routes, if the east-west LRT routes are appropriately spaced and the ferry runs not only across but also along the river, the problem of a direct route would be partially solved. Also, a single ticket purchased at one location for several mode changes might partially solve the problem of higher costs due to mode transfers.

Given the above, the yearly cost per passenger km for the five modes is calculated and

[13] b = 7 kilometers and L = 18 kilometers.

given in Table 10. The costs for each plan may then be determined using unit costs and the kilometers covered by each proposed mode in each plan. We of course multiply the estimates for the sample by a factor of 1680 to obtain cost estimates for the city. These are given in Table 11. Using these cost figures and the figures on 'pollution saved' in Table 9, we obtain the cost efficiency of each plan in kilograms saved per million rupees (Table 12). Possibly due to the higher relative costs of enhancing the metro and ferry services, plans II (buses only), VI (buses and rail) and III (rail only) come out as least cost plans.

Tables 9 and 12 imply the following:

- Plan II (bus only) is the most cost efficient, but also reduces pollution the least
- Plan VI (bus and rail) is the second best in terms of efficiency and reduces pollution by a medium amount
- Plan III (rail only) is 3rd best in terms of efficiency and the pollution reduction is less than for VI – hence this should certainly be abandoned
- Plan VII (bus, then rail, then metro) is fourth most efficient - moreover, the reduction in efficiency is significant, on the other hand it achieves the maximum reduction in pollution
- Plan VIII (bus, and distribute the rest according to convertibility) is close to VII in efficiency but the reduction in pollution is less than for VII, so it clearly is to be abandoned
- Plan IX (distribute all according to convertibility) has less efficiency than VIII and the pollution reduction is close to that of VIII, so this is similarly to be abandoned
- The same is true for Plan V (rail and metro)
- Plan IV (bus and metro) is second worst, and the pollution reduction is less than for VIII
- Plan I (metro only) is the worst in terms of efficiency, and the pollution reduction is less than that for IV.

Therefore if we give sole importance to efficiency, we should choose Plan II (bus only).

On the other hand, if we balance efficiency with the absolute value of pollution reduction, we can consider both Plans VI (bus and rail) and VII (bus, rail, metro). They are second and fourth in terms of efficiency and the pollution reduction is the highest for VII and a medium amount for VI.

V. Concluding Observations

We have, in this paper, concluded that there are three possible alternative modal structures that are best in terms of efficiency and pollution reduction. The first shifts what *can* be shifted of the more polluting modes to buses (most cost efficient but worst in terms of pollution reduction), the second to buses and the rail (second most cost efficient and a medium level of pollution reduction), and the third shifts them to buses, the rail and the metro (medium level of cost efficiency but the maximum level of pollution reduction). In the latter two, the first priority is given to buses (that is, what can be shifted to buses is done so), then to the rail, and finally (in the third case) to the metro. Hence if we confine ourselves to cost efficiency we should choose the 'buses only' plan. On the other hand, if we are only concerned about pollution reduction we should stick to the bus-rail-metro plan. And if we are primarily concerned about cost efficiency but also have pollution reduction in mind, the bus-rail plan should be our choice.

To this we would like to add the following observations. First, the income structure of Kolkata's population is such that their present modal choice is *far from* the most polluting. The major percentage of travel is by walking, followed by the regular private bus. However, a small percentage of travel is being serviced by a large number of low-occupancy and highly polluting vehicles in the city, and their number is growing dangerously. It is the rich and upper middle classes who are causing a rapid enhancement of Kolkata's transport pollution, and therefore it is they who have to be coerced into using low-polluting HOVs. This can only be done by greatly improving the public transport system, mainly in terms of travel time, wait time, travel comfort and access.

Secondly, alternative plans need not concentrate on the metro as the city's sole savior. It has been conclusively proved that not only is the metro very expensive, but also, the travel that *can* be shifted to the metro would not reduce pollution as much as other plans which concentrate on the bus and rail. The general preference of Kolkata's travelers for buses and the existence of an elaborate bus network in the city should not be ignored. Rather, the transport and other related departments should reconsider the total network, make the private and public services more compatible and strictly monitor the private bus service so that they provide a better product. Kolkata's bus service must be made as attractive as that in the cities of the north to convince the city's affluent to depend on it and forget about their two-wheelers and cars, as is the case in some of the larger northern cities. It is not clear why up-market bus services such as executive buses are so limited, especially as they have been very successful on certain routes.

Our work also indicates the significant possibilities of an improved rail service. If our rail service can be made as good as Bombay's, for example, it would solve a major part of our transport problems. The ferry and circular rail have not been favored on a relative scale. However, this may be because respondents were unduly influenced by their present condition.

Whilst the city has several north-south routes, access to these routes emerges as a major constraint. The use of the rail, circular rail and metro would increase enormously if easy and reasonably cheap access were provided – which means several east-west routes with reasonable gaps in-between. We have suggested a light rail transit for this purpose, superior to the tram that is being phased out because of its innate inefficiencies. One can also think of using buses or other modes of transport for this purpose, although buses would not be zero pollution.

Finally, it may be pointed out that a political will to curb the purchase of personal vehicles would be critical in determining the modal structure in the city and the resultant pollution from transport. It would be difficult to make impositions on the nature of the engine or the fuel, at least in the medium run – as evidenced by recent interactions between the judiciary and the state government, which have almost always ended in the relaxation of restrictions and the extension of deadlines. Moreover, improvements in engine or fuel can never lead to zero pollution. Hence the promotion of zero-pollution modes and discouraging the purchase and use of personal vehicles becomes imperative for megacities like Kolkata.

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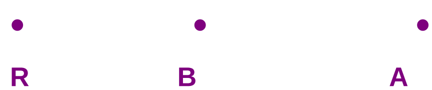
Appendix A: Correction of Data on Travel Frequency

As the data on number of trips is collected on the basis of 'purpose', the frequency of trips becomes overestimated as in reality different destinations may be combined. This has been corrected by using the information on combination trips, which allow us to translate distance corrections into frequency corrections.

Say, for an individual, the (yearly) frequencies for work I and work II are x and y. Say m% of the minor trip (the one with the lower frequency) is combined with the major trip. Then, the combined trips are the product of y and m – call this k.

There are four possibilities. The first three are for the combination of two purposes, which is the usual case, and the last for the combination of three or more purposes.

The first scenario is when the location of work II (B) is on the way to that of work I (A):



The frequency correction will then be as follows:

Work I : x (as before)
Work II: y – k

We simply leave out the combination trips from the second purpose (as we do in the case of all possibilities that will follow), and the frequency for Work I remains the same as the distance traveled does not increase (due to the fact that B is on the way).

Second, work II may be located at a point to the right of the vertical line passing through the location of Work I.

• or B

• • •

R A B

• or B

If the combination is two-way, the frequency correction is as follows:

Work I: (x – k) + k (3/2)
Work II: y – k

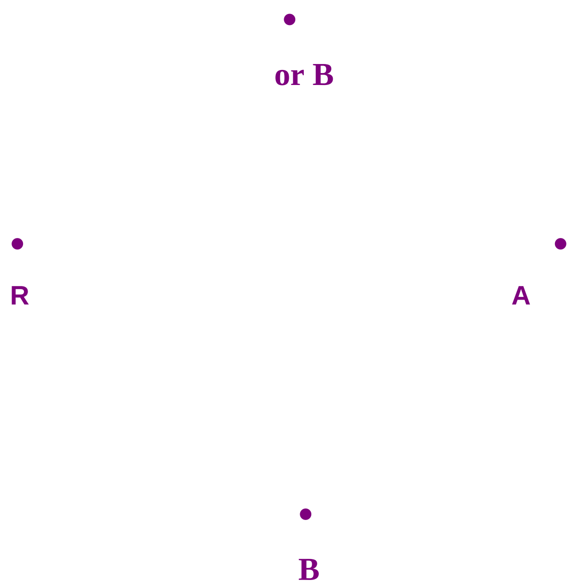
The assumption being made is that on average, the person has to travel half the distance extra to reach B. Thus, trips to work I (A) are divided into two parts: non-combination trips (x-k) and combination trips (one and a half of k). The one and a half times distance is thus translated into a correction of frequency.

If on the other hand, the combination is one-way or circular, the corrections are:

Work I: (x – k) + (k/2)(3/2) + (k/2)(5/4)
Work II: y – k

Here, we are dividing up the trips into two parts (non-combination and combination trips), and the second part is again divided into two parts – the part corresponding to the way that one combines, and the part corresponding to the way that one returns home from B. For the first half of the second part, we assume that B is an extra half distance away from A (on average), and for the second half, as the person goes straight from B back home, so that there is no need to pass through A again, we assume that on average this is one and one-fourth times extra traveling (compared to the distance from R to A) – and hence make the corresponding frequency corrections.

The third case is when B is to the left of the vertical line through A



If the combination is two-way, the correction is:

Work I: $(x - k) + k(5/4)$

Work II: $y - k$.

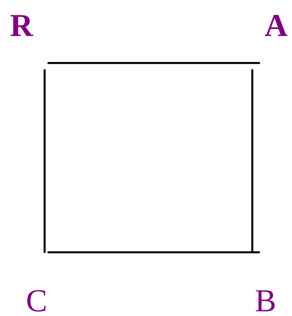
If, on the other hand, it is one-way or circular, the correction is:

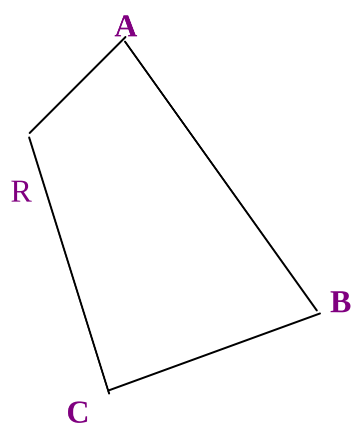
Work I: $(x - k) + (k/2)(5/4) + (k/2)$

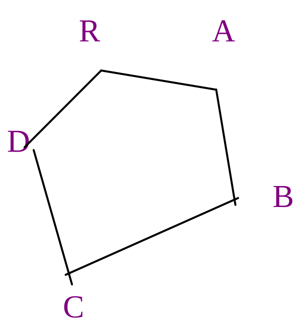
Work II: $y - k$

For two-way combinations we have increased the distance of the combined trips by 25%, an amount half of the increase for the second case when B was further from the residence than A. Further, if the combination is one-way, the distance of one journey remains the same, whilst the distance of the other increases, again by an average of 25%. Hence the above formula.

Finally, for three, four, five etc. trips, which are almost always combined unidirectionally, we have devised the following rules







If three trips are combined, and k is the number of combination trips such that k is the product of z, the frequency of the trip with the lowest frequency, and m, the percentage of this trip that is combined, the correction is

Work I: (x – k) + 2k
Work II: y – k
Work III: z – k

Here we are assuming that on average, the movement makes a square (see the diagram).

If four trips are combined (see the diagram again), we enhance the extra traveling with the assumption that not all the distances are the same, hence we have

Work I: (x – k) + 2.5k
Work II: y – k
Work III: z – k
Work IV: p - k

Similarly, for five trips, we have

Work I: (x – k) + 3k
Work II: y – k
Work III: z – k
Work IV: p – k
Work V: q – k,

And so on.

The decision on the average value of the extra distance is somewhat arbitrary, although there is a certain logic behind each of these values – for example, that if the distance between A and B is more than double the distance between R and A or very much out of the line between R and A, there is little reason for combining the trips. Basically, trip combinations are with the objective of saving travel but also, on a single day, it becomes difficult to travel more than twice of the normal travel distance.

Table 1: Pollution Per Person Per Unit Distance by Mode (gm per person-kilometre)

Mode	Pollution Per Person Per Unit Distance
Three-Wheeler	2.1095
Two-Wheeler	5.1235
Taxi	0.8335
Private Car	0.2900
Regular State Bus	0.0545
Special State Bus	0.0600
Executive State Bus	0.0735
Regular Private Bus	0.1110
Chartered Bus	0.1530
School Bus	0.1635
Mini Bus	0.1055
Shared Taxi	0.5665
Hired Car	0.6900
Ferry	0.0996

Source: Dutta et al, 2008

Table 2: Ranking of Modes

HIGH POLLUTION	Two-Wheeler	1
	Three-Wheeler	2
	Taxi	3
	Hired Car	4
	Shared Taxi	5
	Private Car	6
MEDIUM POLLUTION	School Bus	7
	Chartered Bus	8
	Regular Pvt. Bus	9
	Mini Bus	10
	Ferry	11
	Executive State Bus	12
	Special State Bus	13
	Regular State Bus	14
ZERO POLLUTION	Tram	15
	Metro	16
	Circular Rail	17
	Local Train	18
	Rickshaw	19
	Bicycle	20
	Walking	21

Table 3: Per Capita Monthly Household Incomes in the KMC Area, 2004

Range (Rupees)	Average Income (Rupees)	Percent Households
0 – 125	20	1
126 – 250	221	1
251 – 374	335	8
375 – 624	528	26
625 – 936	801	22
937 – 1248	1135	16
1249 – 2497	1743	17
2498 – 3745	2891	6
3746 – 6241	4792	2
6242 & above	9227	1

Table 4: Total Kilometres Covered by Sample Individuals (Household and Commuter) by Mode

Modes	Kms. covered	Percentage	Rank
Walking	3118565.0	45.83	1
Regular Pvt. Bus	1602869.0	23.56	2
Metro	487363.1	7.16	3
Local Train	313280.7	4.60	4
Rickshaw	224955.8	3.31	5
Three-Wheeler	201695.0	2.96	6
Chartered Bus	197665.7	2.90	7
Bicycle	176286.6	2.59	8
Two-Wheeler	91257.6	1.34	9
Mini Bus	85585.3	1.26	10
Circular Rail	79748.0	1.17	11
Taxi	64622.9	0.95	12
Hired Car	31451.0	0.46	13
Private Car	31096.6	0.45	14
School Bus	25233.0	0.37	15
Ferry	20846.8	0.31	16
Regular State Bus	15864.8	0.23	17
Special State Bus	12728.4	0.18	18
Shared Taxi	10436.6	0.15	19
Tram	8133.8	0.12	20
Executive State Bus	3829.2	0.06	21
Total	6803514.9	100.00	

Table 5: Total Pollution Emitted by Each Mode for Sample

Mode	Pollution (gms.)	Rank
Tram	0	1
Metro	0	1
Circular Rail	0	1
Local Train	0	1
Rickshaw	0	1
Bicycle	0	1
Walking	0	1
Executive State Bus	281.72 (0.02)	8
Special State Bus	763.71 (0.06)	9
Regular State Bus	864.63 (0.07)	10
Ferry	2077.76 (0.17)	11
School Bus	4125.59 (0.34)	12
Share Taxi	5912.33 (0.49)	13
Private Car	9018.01 (0.75)	14
Mini Bus	9029.25 (0.75)	15
Hired Car	21701.19 (1.79)	16
Chartered Bus	30242.85 (2.50)	17
Taxi	53863.18 (4.45)	18
Regular Private Bus	177918.45 (14.71)	19
Three-Wheeler	425475.60 (35.20)	20
Two-Wheeler	467558.31 (38.70)	21
Total	1208832.58 (100)	

Note: percentages are in parenthesis.

Table 6: Convertible Kilometers, by Mode Currently Used, Sample

Mode	Total Km Traveled by Sample	Convertible Kms	Percent of Convertible to Total
Two-Wheeler	91257.6	42480.41	46.55
Three Wheeler	201695	164885.62	81.75
Taxi	64616.4	60804.03	94.10
Hired car	31451	30570.37	97.20
Shared Taxi	10436.6	9758.22	93.49
Private Car	31096.6	21985.30	70.70
Total	430553.2	330483.96	76.76

Table 7: Five Modes to which the More Polluting Modes Can Be Shifted, Kilometers of Possible Shift and Percentages of the Total Kilometers, by Mode, for Sample

Mode	Total Km covered	Shift modes									
		Bus	%	Metro	%	Rail	%	Circular	%	Ferry	%
Two-wheeler	91257.6	5088.2	5.85	27174.8	29.78	17379.8	19.04	12704.6	13.92	3361.8	3.86
Auto	201695	81563	40.44	136075.44	67.47	95285.6	47.24	58377.9	28.94	30255.6	15.00
Taxi	64616.4	26064.7	40.34	55074.66	85.23	32355.7	50.07	39185.5	60.64	15443.4	23.9
Hired car	31451	2512.8	7.99	27977.1	88.95	13287.9	42.25	14560.9	46.3	2006.4	6.38
Shared Taxi	10436.6	4889.4	46.85	9064.2	86.85	4591.4	43.99	4207.2	40.31	2530.4	24.25
Private car	31096.6	2435.9	7.83	7029.24	22.6	1653.8	5.32	2587.2	8.32	2156.8	6.94
Total	**430553.2**	**122554**	**28.46**	**262395.4**	**60.94**	**164554.2**	**38.22**	**131623.28**	**30.57**	**55754.4**	**12.95**

Table 8: Kilometers Corresponding to More Than One Option (Bus, Metro and Rail), Sample

Mode	Total Km covered	Bus & Metro	%	Metro & Rail	%	Bus & Rail	%	Bus,Metro,Rail	%
Two-wheeler	91257.6	4420.1	4.84	8807.5	9.65	3845.5	4.21	3845.5	4.21
Auto	201695	71089.89	35.25	89628.49	44.44	59632.35	29.57	59382.15	29.44
Taxi	64616.4	10338.76	16.00	20604.24	31.89	7835.24	12.13	7809.24	12.08
Hired car	31451	1847	5.87	1296.4	4.12	1268.4	4.03	1268.4	34.23
Shared Taxi	10436.6	3720	35.64	3840	36.79	3720	35.64	3720	35.64
Private car	31096.6	938.2	3.02	950.2	3.06	890.2	2.86	890.2	17.07
Total	430553.2	92354	21.45	125126.8	29.06	77191.69	17.93	76915.49	17.86

Table 9: Pollution Saved in Proposed Plans (thousand kgs.) in KM C Area

Plan	Pollution Saved	Rank
I	840	6
II	350	9
III	550	8
IV	900	5
V	990	4
VI	650	7
VII	1300	1
VIII	1010	3
IX	1030	2

Table 10: Yearly Person-Kilometre Cost Estimates of Running the Five Alternative Modes Proposed in the Plans, 2004

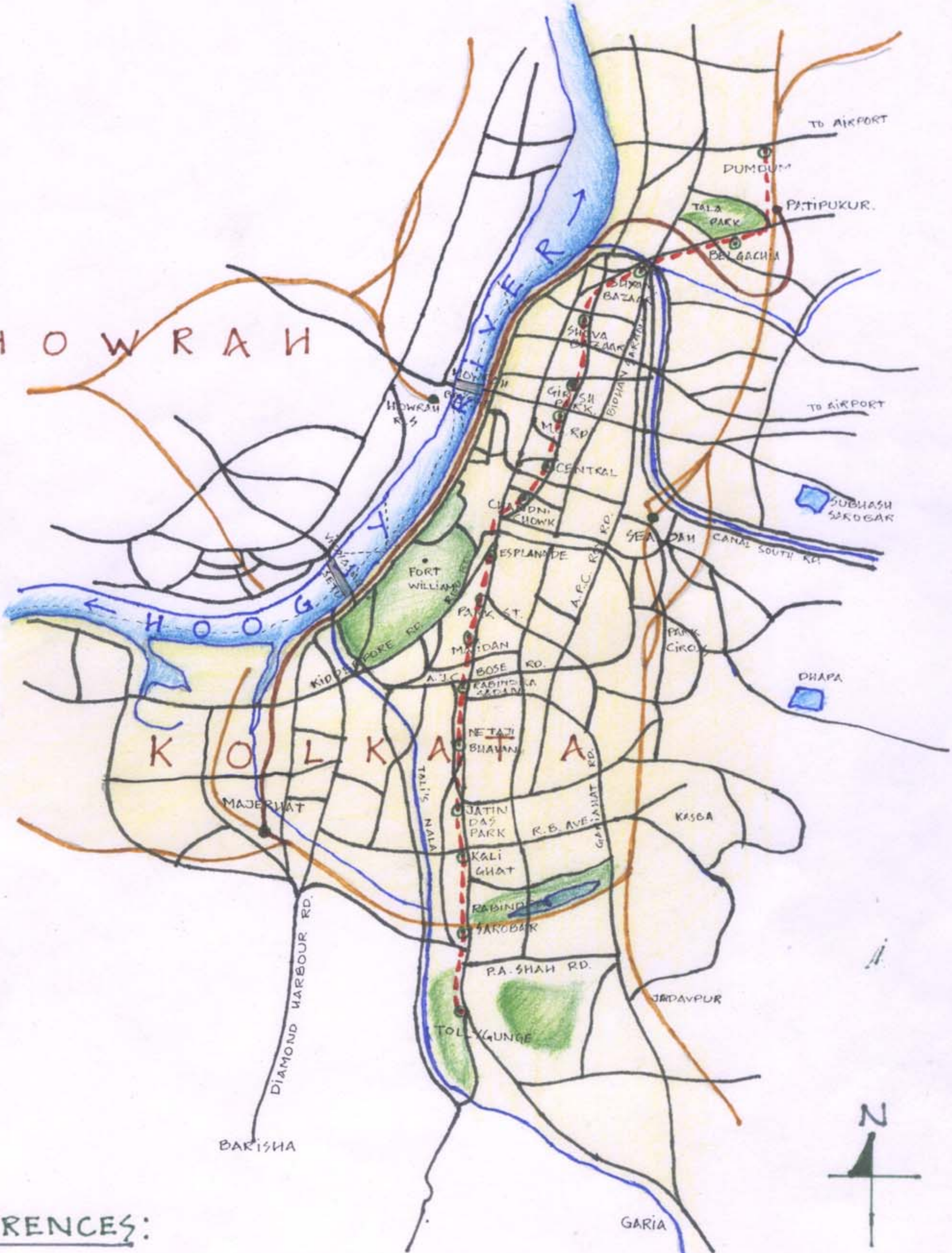
Mode	Operating and Capital Cost (Rupees)	Comfort Cost (Rupees)	Access Cost (Rupees)	Total Cost (Rupees)
Bus	0.30	0.01		0.310
Metro	1.75		0.097	1.847
Rail	0.25		0.194	0.444
Circular Rail	0.25		0.194	0.444
Ferry	0.40		0.388	0.788

Table 11: Yearly Cost of Implementing the Proposed Plans for the KMC Area (million Rupees)

Plan	Cost (million Rupees)
I	806
II	67
III	118
IV	588
V	538
VI	134
VII	504
VIII	450
IX	529

Table 12: Cost Efficiency of Plans (Kilograms of Pollution Saved per Million Rupees)

Plan	Cost Efficiency	
	Value	Rank
I	**1042**	**9**
II	**5224**	**1**
III	**4661**	**3**
IV	**1531**	**8**
V	**1840**	**7**
VI	**4851**	**2**
VII	**2579**	**4**
VIII	**2244**	**5**
IX	**1947**	**6**



REFERENCES:

- CIRCULAR RAILWAY
- MAIN RAILWAY
- METRO RAILWAY
- MAJOR ROAD
- WATER BODIES